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Spatial Disorientation: A Survey of U.S. Army Helicopter Accidents 1987 - 1992

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All class A-C U.S. Army rotary wing accidents for the period May 87 - Apr 92 were reviewed by three flight surgeons acting independently. Those accidents in which spatial disorientation was considered to have played a major role were identified and compared to those in which spatial disorientation played no part. In addition, an attempt was made to identify the factors behind each spatial disorientation accident together with potential solutions.

Of the 583 accidents entered into the study, 32 percent were considered to have had spatial disorientation as the major factor (by which it was meant that there would have been no accident if there had been no spatial disorientation). This is a higher figure than has been reported before, possibly because of differences in definitions. Spatial disorientation cost the U.S. Army $308,887,000 and 78 lives during this period. A distinct trend between various types of night flying and spatial disorientation was evident, the maximum risk being associated with the use of NVG and FLIR (the risk was 10-15 times higher than for ordinary daytime flight). The rate of spatial disorientation accidents was also particularly high during Operations Desert Shield and Desert Storm.

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There were few identifiable episodes of visual or vestibular illusions in this accident series. Classical causes of spatial disorientation - such as 'whiteout', 'brownout' and 'inadvertent entry to IMC' were relatively rare (accounting for 25 percent of the spatial disorientation accidents). By contrast, distraction of the aircrew from maintaining a safe flight path appears to have played a major role. The major potential solutions identified reflect this 'situational awareness' problem. Recommendations include training changes, equipment changes and further research into specific areas.

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Table of contents

List of tables

Table

Introduction

It has long been known that humans cannot maintain straight and level flight if they are deprived of visual cues (Anderson, 1919). It also has long been known that the human organs of balance may not only fail to give sufficient cues for accurate perception of position or motion during aviation, but may actually give erroneous cues (for overviews see Guedry, 1974 and Benson, 1978). Therefore, it should be no surprise that aircrew sometimes fail to achieve a correct sense of orientation in the air, and that some suffer an accident as a result.

There is usually a fair amount of redundancy for orientation cues. Therefore, spatial disorientation (SD) is most likely when the number or quality of the correct cues is reduced, or if misleading cues are given preference. This may happen in a variety of ways depending on flight conditions, equipment used, and other factors, and it is logical to suspect that the importance of SD as an accident cause may change as these factors change. In particular, there could be a potential risk associated with the comparatively poor quality visual cues generated by night vision systems such as night vision goggles (NVGs) and forward looking infrared (FLIR) (Rash et al., 1990; Crowley, 1991; Durnford, 1992). Use of these systems has increased rapidly in the last few years, while flight profiles have become more challenging, aircraft have become more agile, and aircrew workload has increased. These factors, combined with the possibility of fluctuations in the accident rate due to other causes (such as mechanical failure), imply a potential shift in the importance of spatial disorientation as an accident cause.

Two major reviews of spatial disorientation as a factor in U.S. Army rotary-wing accidents cover the period until 1987. Hixson and Spezia (1977) summarized data that had been collected over a 5-year period until 1971. These data suggested that, during the study period, 16.5 percent of fatal accidents (and 7.4 percent of the total accidents) had been caused by spatial disorientation. Vyrnwy-Jones (1988) found that while only 0.4 percent of all accidents could be ascribed to disorientation, the rate was 25 percent for the most severe groups (Class A and B accidents). Other conclusions were that:

- Helicopter instrumentation tended to be inappropriate and inadequate.

- The most common phase of flight associated with disorientation accidents was the approach to land.

- The major causal factors were flight in poor visibility, loss of visual cues due to recirculation phenomena (e.g., brownout), inadvertent entry to IMC, and flight over snow-clad ground.

- The major contributory causes were poor crew coordination, lack of training and experience, use of NVGs, and formation flight.

- Disorientation accidents occurred much more often at night than during the day.

- NVGs were involved in 16 percent of all disorientation accidents.

The above findings are broadly in line with the results from research for other helicopter groups (Edgington and Box, 1982; Vyrnwy-Jones, 1985); however, the data on which they are based are now 6-10 years old. The purpose of this study was to update the data with the specific aims of:

- Discovering the number of accidents in which spatial disorientation (SD) was implicated.

- Comparing accidents involving SD with other accidents in order to determine particular patterns associated with SD accidents.

- Identifying areas for further research.

- Suggesting better investigation and data recording methods for SD accidents, if applicable.

- Recommending potential solutions.

Methods

Summaries of all Class A-C Army rotary-wing accidents occurring from 1 May 1987 to 30 April 1992 were obtained from the U.S. Army Safety Center (USASC) at Fort Rucker, Alabama. Three flight surgeons (S.J. Durnford [SJD], Norberto R. Rosado [NRR], and J.S. Crowley [JSC]), acting independently, reviewed each accident summary and extracted information onto a copy of the form at Appendix A. This form asked for the researcher to classify the accident according to the role of SD and to answer various questions (most of which were only applicable if SD played an important role). In addition, the noncontentious statistical information listed in Appendix B was extracted from the USASC computer for all accidents whether due to SD or not.

Accidents were classified by each researcher into one of the following groups:

- Class 1. SD was the major component of the accident sequence (which meant that all other contributory factors normally would have been overcome without mishap).

- Class 2. SD was a subsidiary component of the accident sequence (which meant that other contributory factors would have led to a mishap in any case, but SD made the accident sequence more difficult to deal with or the outcome more severe).

- Class 3. SD was an incidental component (which meant that SD occurred but did not affect the outcome).

- Class 4. SD did not occur.

- Class 5. The role of SD was unknown.

The minimum standard for all assessments was not one of absolute certainty, but was one of more probable than not in the view of the researcher. This was because proof of SD often is absent following an accident, and what was sought was the most accurate picture rather than the picture that was most provable. However, each researcher was asked to score how confident they felt about the role of SD in each accident.

Accidents about which there was a conflict of opinion were the subject of a meeting. The protocol allowed for a mechanism to deal with cases where no consensus could be achieved, but it proved unnecessary. Following this final classification of each accident, the information pulled from the USASC computer was used to compare accidents due to SD (class 1 accidents) and those where SD played no real part (classes 3 and 4). Unless otherwise specified, all comparisons were based on chi-square testing.

In addition, the opinions of the researchers expressed on the completed accident forms were collated and analyzed, yielding information on the importance of various factors such as vestibular/visual illusions.

Definitions

For the purpose of this study, the definition of spatial disorientation was that given by Benson (1978), namely the situation occurring "...when the aviator fails to sense correctly the position, motion or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the earth, and the gravitational vertical." Also used was Vyrnwy-Jones (1988) additional clause including the erroneous perception of "... the aviator's...own position, motion or attitude to his aircraft, or of his aircraft relative to another aircraft...". As usual, "geographic disorientation" (getting lost) was specifically excluded.

Contact with an obstacle known to be present, but erroneously judged to be sufficiently separated from the aircraft, was included as spatial disorientation. Contact with an obstacle whose presence was simply unknown was not considered spatial disorientation, unless it was associated with other manifestations.

Pilot study

A pilot study was undertaken prior to the main study using data from 50 previous accidents. This permitted fine tuning of the procedures and definitions. The accidents used for this pilot study date from before 1 May 1987, and therefore do not form part of the data presented here.

Results

Of the 607 Class A-C accidents during the period, 583 were entered into the study. The remaining cases were either simple listings of other aircraft involved in multiple-aircraft accidents, or had been reclassified lower than Class C by the time computer analysis began.

The role of spatial disorientation

Table 1 shows the role of SD as an accident cause for the period under study.

Table 1.
The role of SD as an accident cause.

	Number (%) of all accidents
SD was considered the MAJOR factor	187 (32%)
SD was considered a CONTRIBUTORY factor	13 (02%)
SD was considered an INCIDENTAL factor	8 (01%)
SD was considered NOT TO HAVE OCCURRED	359 (62%)
SD played an UNKOWN role	16 (03%)

Certainty of classification

In general, confidence that accidents had been correctly classified was high. Two researchers felt less confident about the classification of SD accidents than non-SD accidents ($p=0.022$ and $p<0.0001$ respectively on chi-square testing). One showed no significant difference ($p=0.65$).

Table 2 shows how many SD accidents fell into each level of certainty, broken down by researcher. (Levels of certainty for non-SD accidents were higher.)

Table 2.
The percentage of SD accidents allotted to each level of certainty by each researcher.

Researcher	Likely to be right 95 out of 100 times	Likely to be right 3 out of 4 times	More probable than not
JSC	61%	18%	21%
SJD	59%	16%	25%
NRR	94%	5%	1%

The cost of spatial disorientation in money terms

The mean cost of the accidents in which SD was the major factor was significantly greater than the mean cost of the accidents in which SD did not play a part ($p=0.000155$ on t-testing). Details are in Table 3. Total cost of SD accidents was $308,887,000.

Table 3.
The cost of spatial disorientation and nonspatial disorientation accidents in money terms.

	Accidents in which SD was the major factor	Accidents in which SD did not occur or was incidental	Other accidents
Total cost	$308,887,000	$283,576,000	$29,115,800
Mean	$1,651,802	$772,686	$1,213,158

The cost of spatial disorientation in terms of lives lost

The mean number of lives lost per SD accident was significantly higher than the mean number lost per non-SD accident ($p=0.0017$ on t-testing). Details are in Table 4.

Table 4.
The cost in lives lost for spatial disorientation and nonspatial disorientation accidents.

	Accidents in which SD was the major factor	Accidents in which SD did not occur or was incidental.	Other accidents
Lives lost	78	51	24
Mean	0.417	0.139	0.828

Of the 78 deaths associated with SD, 72 occurred at night. The lethality of SD accidents was greater at night than during the day (mean lives lost 0.65 compared with 0.09, $p=0.0068$ on t-testing).

In comparison, only 12 of the 51 deaths associated with non-SD accidents occurred at night. There was no significant difference in lethality by day or by night ($p=0.74$ on t-testing).

The higher cost of SD accidents in terms of lives lost is not explained by higher passenger loads, since there was no significant difference in mean occupancy rates for SD accidents compared to non-SD accidents (3.39 and 3.43 respectively, p=0.882 on t-testing). Furthermore, there were significantly fewer uninjured occupants in SD accidents compared to non-SD accidents (2.17 against 2.79, p=0.03 by t-testing).

SD accident rates by day and night

Chi-square testing showed a highly significant relationship between <u>unaided</u> night flight and the incidence of SD (p=0.00114, Saudi data excluded). Similarly, there was a highly significant relationship between <u>aided</u> night flight and SD (p=0.00000, Saudi data excluded). Including the data from Saudi strengthened the p value in both cases.

There was no significant difference between aided and unaided night flight (p=0.09, Saudi data excluded), and there was no significant difference between NVG and FLIR (p=0.751).

Taking all data, there was an increase in the rate of SD accidents for AN/AVS-6 compared to AN/PVS-5 (p=0.026). This pattern may reflect the disproportionate use of AN/AVS-6 in Saudi, since the pattern becomes insignificant once Saudi data are excluded (p=0.13).

Flying hours by day, night/unaided, night/NVG, and night/FLIR (AH-64) were available for the years 1990 and 1991. A breakdown of the different rates for SD and non-SD accidents per 100k flying hours is given in Table 5. The increase in SD accidents at night contrasts starkly with the steady rate for non-SD accidents. It should be noted, however, that this time span includes the Gulf War period (and separate flying hours were not obtained for this study).

Table 5.
SD and non-SD accident rates (per 100k flying hours) broken down by day, night/unaided, night/NVG and night/FLIR (data only available for 1990-91).

	Total flying hours (FH) 1990-91	Accident rate (per 100k FH) for accidents in which SD was the major factor.	Accident rate (per 100k FH) for accidents in which SD did not occur or was incidental.
Day	2,071,400	1.45	6.08
Night/unaided	218,109	5.50	4.13
Night/NVG	263,557	17.83	5.31
Night/FLIR	37,248	21.48	5.37

Variations in SD rates by aircraft type

Chi-square testing indicates that aircraft type differences are significant (p=0.021), with the UH-60 and the AH-64 showing higher than expected rates of SD. These differences might conceivably reflect a number of factors ranging from mission profiles to night flying equipment. It is interesting that if the data from the operations in Saudi Arabia are removed, the significance falls to borderline levels (p=0.06).

Table 6 gives the rates of SD per 100k flying hours broken down by aircraft type. Flying hours were available on an annual basis for the full period. However, since the accident data for the years 1988 and 1992 were incomplete, these years were excluded from the analysis.

Table 6.
Aircraft type differences*.

AC type	Percent of accidents due to SD	Total flying hours (FH) 1989-91	Total accidents per 100,000 FH	SD accidents per 100,000 FH
UH-1	25	2,525,302	4.6	1.2
OH-6	17	127,339	10.2	2.4
OH-58	33 (A-C)	1,152,994 (A-D)	8.5 (A-D)	3.2 (A-D)
	35 (D)	FH not broken down by model		
AH-1	38	535,268	11.0	4.5
CH-47	20	217,903	21.1	4.6
UH-60	44	685,254	9.8	4.7
AH-64	38	283,477	17.3	6.3

*All models of aircraft were included except where noted for the OH-58.

Seasonal effects

The following seasonal patterns were evident (Saudi Arabia data have been excluded):

- There were no significant seasonal variations for SD rates (against non-SD rates) for daytime accidents ($p=0.57$).

- For nighttime accidents, summer was the worst season for SD accidents while spring was the best ($p=0.012$). (See Table 7.)

Table 7.
Chi-square test observed versus expected numbers of nighttime SD accidents by season. Saudi data have been excluded.

Season	Actual number of SD accidents	Expected SD accidents*
Spring (Mar, Apr, May)	15	21
Summer (Jun, Jul, Aug)	29	21
Autumn (Sep, Oct, Nov)	21	23
Winter (Dec, Jan, Feb)	17	16

* Expected numbers calculated using the standard X^2 formula

Analysis by month rather than by season also shows significant nighttime patterns (p=0.0066) but no significant daytime patterns (p=0.2). The worst months for SD accidents at night were August, November, and June; the best were April, October, and May.

Annual trends

Taking full year data only (i.e., 1988-1991) and excluding the data from Saudi Arabia, the following patterns emerge:

- In contrast to the seasonal variation, there is no significant variation in SD rates across the years for nighttime accidents (p=0.174).

- There is, however, a significant variation for daytime accidents (p=0.0036) as shown in Table 6. Bad years were 1988 and 1991, good years were 1989 and 1990.

Table 8.
Observed versus expected numbers of daytime SD accidents by year. Saudi data have been excluded.

Year	Actual number of SD accidents	Expected number of SD accidents*
1988	20 (higher than expected)	11
1989	8 (low)	14
1990	11 (low)	14
1991	17 (high)	13

* Expected numbers calculated using the standard X^2 formula

Geographical location

There were no apparent differences in SD rates between individual states (p=0.1 on chi-square testing) or between the U.S. and other countries (p=0.1 with Saudi data included, p=0.87 once Saudi data were excluded).

When the data from Saudi were compared with data from other locations, there was a higher than expected rate of SD accidents associated with night flying (p=0.0084 on chi-square testing), but no apparent daytime variation (p=0.1). A massive 81 percent of nighttime accidents in Saudi were ascribed to SD (for all accidents the figure was 50 percent).

Terrain

In 87 percent of accidents, the terrain was reported in the USASC database as flat, rolling, water, desert, mountains, or some mix of these categories.

There were only borderline significant differences in the SD rates for these different terrains (p=0.061, Saudi data included, p=0.054 with Saudi data excluded). Flat was associated with lower than expected rates of SD, while rolling was associated

with increased SD rates. These results are counterintuitive, given the known problems posed by water, desert, and mountains. They may be chance findings.

Review of the data showed a particularly high SD rate associated with Saudi when compared to other desert locations ($p=0.0071$). As with all the Saudi data, this appeared to be a nighttime phenomenon ($p=0.128$ by day, $p=0.0022$ by night).

Flight profiles

Accidents involving SD as the major factor were associated with significantly lower altitudes at the onset of the emergency than accidents in which SD did not occur or was incidental (mean=44 compared to mean=490; $p=0.00003$).

Similarly, they occurred at a lower airspeed (mean=31kts compared to mean=43 kts; $p=0.00222$).

There was no difference in the mission duration (mean=1.2 hrs compared with mean=1.0 hrs; $p=0.10$).

Flying hours

T-testing revealed no significant differences in the mean flying hours for crew involved in SD accidents compared to those involved in non-SD accidents. This was true whether the data were compared for the handling pilots alone or for both crew together, and it was true for both the total career flying hours and the flying hours in the past 30 days. It remained true when the data were broken down by day, night, night unaided, and night aided.

Mean flying hours per pilot was 1567. Mean flying hours in the previous 30 days was 17.

Division of experience between aircrew

The division of experience between the aircrew did not appear to be a factor. The flying hours gap between the pilot-in-command (PIC) and the copilot was not significantly different when SD accidents were compared to non-SD accidents.

Sex

Only 13 accidents involved female aircrew. There were no detectable significant differences in the rates for SD versus non-SD accidents.

Safety Center coding

Only 20 accidents had been coded as SD by the USASC. We agreed with this coding in all 20 accidents, but considered that an additional 167 had involved SD as the major factor.

Inadvertent entry to IMC

There were 17 accidents coded by the USASC as involving inadvertent entry to IMC. Twelve had also been coded by the USASC as being due to SD. We additionally classified four of the others as SD accidents and one as unknown. Thus, 8.6 percent of SD accidents involved inadvertent entry to IMC. Of these 88 percent, 15 occurred at night.

Solo vs. nonsolo

There were 88 solo accidents, of which 23 were SD. The difference in SD vs non-SD rates was insignificant, whether the data were considered overall or were broken down by day, night, night unaided, or night aided.

Number of crew disoriented

Crew numbers were not explicitly available to researchers as they reviewed each accident. In 72 (39 percent) of SD accidents, two or more researchers deduced from the accident history that both front seat crew had been disorientated. In contrast, two or more researchers deduced that only one in six pilots had been disorientated (3 percent).

Sleep in the 24 hours prior to the accident

Overall, there was no significant difference in the mean sleep duration of the pilots involved in SD accidents when compared to the mean sleep duration for those involved in non-SD accidents. This was true when both crew were considered together as well as for comparisons of the handling pilots alone. Breaking down the accidents by day, night, and night unaided had no effect. Night/night vision device (NVD) accidents, however, showed a lower mean sleep duration for SD accidents than for non-SD accidents (mean=8.26 hours against 8.9 hours, $p=0.039$). This may be a chance finding since the difference appears to be due to a longer than usual mean sleep duration for non-SD accidents rather than the other way round.

There was a highly significant difference in the sleep levels enjoyed by crew involved in day accidents (whatever the cause) compared to those involved in night accidents (mean=7.98 hours for day and 8.47 hours for night, $p=0.00005$). This may reflect increased daytime rest taken by crews scheduled to fly at night.

The effects of mission type

The association between high SD rates and flying in Saudi Arabia during the Gulf War has been alluded to earlier. In addition, chi-square testing of mission type, as recorded in the USASC data, shows a significant variation, with combat and training missions having comparatively high rates of SD and

service and maintenance flights having comparatively low rates (p=0.00033).

Distraction

When reviewing each accident (whether attributed to SD or not), researchers were asked to check a box stating whether or not the aircrew had been distracted prior to the onset of the emergency (see page 1 of the form at Appendix A). When the data from each researcher was individually subjected to Chi-square testing, there was a consistent and highly significant relationship between SD accidents and pilot distraction. This was true whether the distraction was inside or outside the cockpit (p for all analyses).

Two or more researchers agreed there was a distraction inside the cockpit in 24 percent of SD accidents and agreed that there was a distraction outside the cockpit in 26 percent. (For comparison, the figures for non-SD accidents are 5 percent and 3 percent respectively.) In some accidents, there were distractions both inside and outside the cockpit. In total, two or more researchers agreed that there had been some distraction (whether inside or outside the cockpit) in 44 percent of SD accidents.

There were no significant day/night effects on the likelihood of aircrew being distracted (p=0.38 on chi-square testing). Neither was there a significant difference in aircrew distraction rates for the wartime data from Saudi compared to the data from elsewhere (p=0.24).

Type of spatial disorientation and duration of episodes

Disorientation is labelled type 1 when aircrew are unaware that they have a problem and type 2 when they are aware that they have a problem. In 73 percent of the SD accidents, two or more researchers agreed that the SD experienced was of type 1. The figure for type 2 was 18 percent.

Researchers were asked to estimate, where they felt it to be possible, the length of time for which aircrew had been disorientated prior to each accident. Estimates should be treated as very tentative; they ranged from 2-60 seconds, with a mean of 9 seconds.

Medical waivers and drugs

Chi-square testing revealed no significant difference between aircrew involved in SD accidents and those involved in non-SD accidents in respect of medical waivers or positive tests for alcohol or drugs.

Researcher opinions

The form at Appendix A gives the questions each researcher had to answer for each accident. They can be grouped into questions relating to misjudgments of flight parameters, questions relating to specific accident features, questions relating to sensory failures (including illusions), and questions relating to potential solutions.

For each question, the yes, maybe, and no answers were scored (on a scale of 3, 2, 1 respectively) and then were totalled, for each researcher individually, across all accidents. These sum totals were then ranked within each question group described above. Rankings then were compared across all three researchers (using Friedman testing and Candle coefficients of concordance) in order to ascertain the relative importance of each factor and the degree of researcher agreement. Tables 9-12 list the rankings (broken down by day, night unaided, and night/NVD where appropriate).

Because the rankings only show the importance of factors <u>relative</u> to each other, the tables show also the overall percentage of SD accidents in which two or more researchers agreed on a yes answer. This gives an indication of the absolute importance of each factor.

Table 9.
Researcher opinion on flight parameters misjudged by aircrew.

Misjudged flight parameter	Percent of SD accidents in which two researchers agreed a yes answer	Rank by day	Rank by night unaided	Rank by night/ NVD
Crew misjudged clearance to the ground or a terrestrial object	65	1	1=	1
Crew misjudged altitude	36	2	1=	2
Crew misjudged rate of descent	24	3	3	3
Crew misjudged speed	3	4	4	4
Crew misjudged angle-of-bank	2	5	5	6=
Crew misjudged pitch angle	2	6	6	6=
Crew misjudged clearance to another AC	4	7	7	7
Friedman probability	N/A	<0.011	<0.012	<0.006
Kendall C of C	N/A	.921	.904	.994

Factors achieving equal importance on ranking have been annotated with an '=' sign rather than a fractional mean rank.

Table 10.
Researcher opinion on potentially important accident features.

Potentially important accident features	Percent of SD accidents in which two researchers agreed a yes answer	Rank by day	Rank by night unaided	Rank by night/ NVD
Unintentional AC movement	25	1	1	2
Brownout	14	2	2	1
Whiteout	2	3	4	4
Illusion of sideways movement due to downwash	1	4	7	3
Illusion of climb due to downwash	0	5	6	5
Illusion due to sensor remoting or sensor movement	0	6	3	6
Flicker vertigo	0	7	5	7
Friedman probability	N/A	<0.012	<0.014	<0.048
Kendall C of C	N/A	.863	.887	.705

Table 11.
Researcher opinion on sensory failures and problems.

Sensory difficulty	Percent of SD accidents in which two authors agreed a yes answer	Rank by day	Rank by night unaided	Rank by night/ NVG	Rank by night/ FLIR
Insufficient visual cues	39	1	1	1	1
Provocative maneuvering	6	2	3	4	4
Insufficient vestibular cues	12	3	2	3	3
Visual illusion	2	4	4	5	7
Vestibular illusion	1	5	5	6	8
Visual limitations of NVDs	59 (NVD accidents only)			2	2
Failed to attend NVD symbology	29 (AH-64 accidents only)				5
Misinterpreted NVD symbology	0 (AH-64 accidents only)				6
Friedman probability	N/A	<0.027	0.09	<0.040	<0.020
Kendall C of C	N/A	.911	.661	.78	.89

Table 12.
Researcher opinion on potential solutions.

Potential solutions	Percent of SD accidents in which two authors agreed a yes answer	Rank by day	Rank by night unaided	Rank by night/NVD (excl inj symb)	Rank by night/ NVD (excl AH64)
Crew coordination	45	2	1	1	1
Better scanning	36	1	3	2=	2
Height audio warning	15 (22 of NVD cases)	4	2	2=	3
Injected symbology in NVGs	22 (NVG cases only)				4
Hover lock	19	3	4	4	5
Drift indicator	14	6	7	5	6
Peripheral vision device	0	5	5	7	7=
Better instruments	1	7	6	5	7=
Better visibility devices on AC	0	8	10	8	9
Better NAVAIDS	1	9	8	9	10
Better cockpit lighting	0	10	9	10	11
Friedman probability	N/A	<0.0023	<0.0032	<0.005	<0.0045
Candle C of C	N/A	.953	.917	.873	.849

Factors achieving equal importance on ranking have been annotated with an '=' sign rather than a fractional mean rank.

Discussion

Much of the cited data are self-explanatory or have been recorded simply so that future comparisons can be made. Discussion will be limited to areas of particular interest or importance.

Interpretation of the results

Our intention has been to produce a descriptive rather than an analytical study. We have made no attempt to allow for p-inflation since we wanted to identify areas for further work rather than deliver categorical statements. Similarly, we have made no allowances for the fact that some factors may influence both sides of the comparison between SD and non-SD accidents. (For example, there may be links between aircraft type and engine reliability as well as between aircraft type and the likelihood of SD.) The comparative rates per 100k flying hours, where given, may be a better source of information than the bald chi-square results. Readers are encouraged to draw their own conclusions from our data and statistics.

Reliability of results

A decision as to the cause of an accident sometimes may be difficult. This means that surveys like this are inevitably based on opinions and perceived probabilities (and the data used to generate these opinions are often the product of someone else's perceptions already). We were keen to obtain as accurate a picture as possible of the current importance of SD as an accident cause, but we were very aware that the results would inescapably reflect opinion as well as fact. In order to try and estimate how "hard" our results were, we tasked ourselves with assessing for each accident how certain we felt about the accident cause.

Although, in general, we felt less certain about SD accidents than we did about non-SD accidents, it is interesting that we felt reasonably certain about most. Individually, we

thought that we would be right at least 3 out of 4 times in 75-99 percent of the accidents we ascribed to SD (and we thought that we would be right 95 times out of a 100 in 59-94 percent). We therefore believe that our results reflect an accurate picture of the influence of SD on U. S. Army accident rates for the period given. If there is any bias, it might act in either direction.

Comparisons with Safety Center codings

There was a large disparity between the number of accidents that we ascribed to SD (187) and the number ascribed to SD in the U.S. Army Safety Center codings (20). This is due, in part, to semantics because spatial disorientation means different things to different groups of people. A further reason may be the gray area that surrounds all human factor accidents. Boards of inquiry and accident coders may see what they expect to see or what they feel comfortable with. If they have not been primed to watch for SD, they may not consider it, or may ascribe accidents to related factors such as lack of crew coordination.

The cost of spatial disorientation

Our results indicate that SD costs the U.S. Army approximately 15 lives and $60 million a year.

Our findings also agree with those of previous investigators (i.e., Hixson and Spezia, 1977; Vyrnwy-Jones, 1988; Edgington and Box, 1982) in that SD accidents appear to be significantly more costly in terms of both money and lives than non-SD accidents. This may reflect a number of possible factors ranging from aircrew being unaware of the impending accident (and thus making no mitigating control inputs) through to higher SD rates for more modern and more expensive aircraft. Whatever the cause(s), a reduction in SD rates would save a substantial number of lives and a considerable amount of money.

Furthermore, unless measures are taken to reduce the incidence and severity of SD, there may well be an increase in the cost of SD in line with increasing night flying operations.

(The SD rates per flying hour suggest an increased risk associated with the use of night vision devices of more than 10:1 compared to daytime flying.)

Spatial disorientation and combat

The increased risk of SD during the Gulf War was anticipated. (The finding that 50 percent of losses in Saudi Arabia involved SD as the major factor links with previous data suggesting that 60 percent of losses involved SD to some degree or another, as reported by Murdock, 1993.) The question remains whether the increased risk was associated with the reduced safety margins and increased pressures of war, or whether it was associated simply with the difficulties of desert flying. The fact that the significant increase in SD accidents persisted when Saudi data were compared to data from other desert locations adds weight to evidence from other studies indicating a wartime effect on SD (Durnford, 1992; Vyrnwy-Jones, 1988).

The fact that the increased risk in Saudi appears to have been a nighttime phenomenon is especially worrying, since the non-Saudi data that we used for comparison already show a significant association between night flying and SD. Owning the night does not come without risks; we ascribed 81 percent of Saudi nighttime losses to SD.

Also, it is worth noting that the operational costs of SD are not limited to aircraft losses since as few as 3 percent of episodes of SD actually lead to accidents (Durnford, 1992). Therefore, a high SD accident rate implies an extra loss of operational efficiency due to SD incidents of varying severity.

The nature of SD

This study confirms the wide-ranging nature of SD in U.S. Army helicopter operations.

The well known causes certainly exist but do not appear to be predominant. For example, brownout, whiteout, or inadvertent

entry to IMC account for a total of only 25 percent of the SD accidents. By contrast, aircrew distraction was thought to play a part in 44 percent of SD accidents, while misjudgment of clearance to the ground or a terrestrial obstacle was thought to play a part in 65 percent. The typical picture is less one of a classical illusion or an environmental problem than one of hard-pressed aircrew, flying a systems intensive aircraft under NVD, failing to detect a dangerous flight path. This matches with the high proportion of type 1 incidents found in the study (classical SD episodes such as inadvertent entry to IMC or recirculation problems would be more likely to be type 2). It also matches with a failure to find any significant geographical distribution of SD (with the exception of the concentration of SD accidents in Saudi during wartime).

Other textbook conditions, such as flicker vertigo or illusions due to downwash, proved almost nonexistent in our accident database. Similarly, there were no obvious cases of vestibular illusions, although we cannot by any means rule out low grade vestibular disturbances.

By comparison, the role of poor visual cues was highlighted by the relationship between SD and night flight and by the high percentage of accidents in which the inadequacies of NVDs were considered to have played a part (59 percent of NVD accidents). The figures in Table 5 (showing the SD accident rates per 100k flying hours broken down by day, night unaided, and night aided) must be serious cause for concern.

Contributory factors

It is reassuring that sleep, drugs, medical waivers, aircrew experience (and cockpit gradient), solo flying, and aircrew sex all appear to be factors that are unrelated to SD accident rates. This should not be allowed to lead to complacency in monitoring these areas.

In particular, it is worth noting that no evidence could be found of a link between currency (as defined by flying hours in the previous 30 days) and the likelihood of an SD accident. NVD

flying is considered to be a highly perishable skill; given the relationship between night flying and SD one might expect a link between currency and SD. It might be that the accident numbers involved are too small to be sensitive to slight variations in currency, or it might be that aircrew with less currency give themselves greater margins for safety.

Variations by aircraft type

The types most associated with SD (in terms of accident rates per 100k flying hours) are the UH-60 and AH-64. Both have features that might be considered as potential factors in SD: the UH-60 has window pillars blocking a part of the view from the cockpit, and the AH-64 is equipped with an IR night-imaging system. However, there are several other potential factors at play, such as combat roles, and it would be rash to draw any conclusion other than that aircrew flying modern missions in modern aircraft appear to be at greater risk than ever before. This fits with the situational awareness type of SD so prominent in our accident series.

Day and night influences

The highly significant relationship between night flying and SD was no surprise. The strength of the association was highlighted in that 72 of the 78 deaths associated with SD occurred at night. Why nighttime SD accidents should be so much more lethal than daytime SD accidents is a question that bears further research. It is possible that the reduced visual cues at night make it more difficult to mitigate the effects of SD.

Also interesting, using the data for the whole period, there was no significant difference between aided and unaided night flight or between NVG and FLIR on chi-square testing. Nonetheless, the SD rates per 100k flying hours in Table 5 show a highly disturbing trend. This table covers the period 1990-1991 only, since flying hour data were available only for these years. Chi-square analysis of the data from this period (excluding Gulf War data) shows the expected significant difference in SD rates

between aided and unaided night flight (p=0.026), but no difference between NVG and FLIR. (It should be noted that accident numbers in the latter two categories are small.) Comparisons between aided and unaided night flight are not easy. Although unaided flights are flown at greater altitude and may be technically more simple, they are flown blind in the sense that the aircrew have no access to even the degraded vision available with NVDs. On the other hand, NVD flights are flown in a more challenging fashion near to the ground and the NVDs themselves, of course, may cause illusions. Our results indicate that the current use of NVDs is associated with increased risk of SD.

Seasonal and annual trends

It is interesting that seasonal trends in SD accidents appear to affect only nighttime flying. It would be tempting to ascribe this to interactions between weather and night if it were not for the unexpected finding that summer appears to be the worst season. This is another area which would benefit from further research. Possible contributing factors include workload differences and circadian influences.

It is also difficult to pinpoint the causes of the highly significant but inconsistent variations in annual SD rates. Since these variations apply only to daytime rates, implications are that the factors involved are different to those influencing seasonal rates. It is possible they reflect command style influences such as attention to safety margins and risk factors. The swinging pattern may be self-fuelling in that accident rates may lead to shifts in flight safety emphasis which in turn affect accident rates. (1988 was a bad year, 1989 and 1990 were good years, while 1991 was another bad year.) In areas such as SD, it is dangerous to become complacent.

Potential solutions

It was a salutary experience to find that the potential solution most often identified by the researchers was nothing to do with technical hardware but was simply increased crew

coordination. This factor was considered to have been potentially beneficial by two or more researchers in 45 percent of the SD accidents. This does not conflict with suspicions of two or more researchers that both front seat crew had been disorientated in 39 percent of accidents because many accidents were type 1. In these, better allocation of crew duties (e.g., one pilot with his head inside and one with his head outside) might have meant that at least one crewmember would have escaped disorientation.

Allied to better crew coordination was another frequently identified potential solution, improved scanning, which was checked by two or more researchers in 36 percent of SD accidents. Training is in hand in the aviation community to improve these factors.

As far as hardware solutions are concerned, the most immediately benefit would appear to be the introduction of an audio warning on the radar altimeter. This is lacking in many aircraft, including the Apache, despite the fact that the technology is on the shelf and cheap. Given the situational awareness demands on modern aircrew, it seems imprudent to ignore this simple and highly beneficial device. An audio warning was considered to have been potentially beneficial by two or more researchers in 22 percent of NVD SD accidents.

Another frequently quoted hardware solution of particular importance to night flyers was the NVG HUD (or injected symbology for NVDs). This was also considered potentially to be beneficial in 22 percent of NVD SD accidents. It should be remembered, however, that the provision of symbology does not mean that aircrew will pay attention to it. Furthermore, symbology superimposed on the outside scene in a NVD may be distracting or may block off external cues. On the other hand, it provides information to the aircrew which would not otherwise be available to them unless they go head down. To utilize the symbology effectively, aircrew must be taught to scan across from outside cues to the symbology and back, similar to scanning from one instrument to another when instrument flying. Aircrew were considered to have ignored the available symbology in 29 percent of night Apache accidents which reinforces this point.

Other hardware solutions considered to be of potential benefit included hover-locks, to enable aircrew to hold a hover with comparatively low workload, and drift indicators. The former was checked by two or more researchers in 19 percent of SD accidents, the latter in 14 percent.

Peripheral vision devices (Malcolm Horizons) and other improvements in general instrumentation do not appear likely to be of great benefit. This may reflect the different nature of helicopter SD when compared to fixed-wing SD.

Conclusions

SD is an important source of attrition of U.S. Army rotary-wing aircraft, costing $60,000,000 and 15 lives annually. There are indications that it is an increasing problem; the ten to fifteen-fold increase in risk associated with night/NVD when compared to day flying is of serious concern.

The proportion of accidents that could be attributed to SD increased significantly during the Gulf War. Similar findings from other war zones (e.g., the Falklands) suggest that combat may lead to lowered safety margins. Eighty-one percent of nighttime accident losses in Saudi Arabia could be attributed to SD which highlights the potential military implications of this problem.

The typical SD accident is not one of classical vestibular or visual illusions giving a pilot vertigo, but is one of loss of situational awareness leading to contact with the ground or an obstacle. The conditions which predispose to type 2 SD, such as whiteout or inadvertent entry to IMC, are likely to be well known to aircrew. The finding that better crew coordination (or scanning) might have prevented several of the accidents suggests that aircrew are less likely to be aware of the risk of distraction leading to type 1 SD. This aspect is open to training.

Of hardware solutions, audio warnings on radar altimeters and NVG HUDs would appear to be the most likely to be cost beneficial. Increased automation (such as hover locks) and more specific helicopter instrumentation (such as drift indicators) should also be pursued. Pilot workload capacity should be considered as a finite resource requiring careful management. If we are to avoid further costly accidents, we must focus on improving situational awareness and, in particular, that subset of situational awareness dealing with spatial orientation.

Recommendations

- Aviation commanders at all levels be made aware of the potential threat that SD poses during peace and war.

- Aircrew receive detailed refresher training on the causes, manifestations, and effects of SD at least every 3 years.

- Current SD materials, being taught to aircrew, be updated to include the results of this survey (and the importance of equipment such as audio height warnings).

- The use of standard aircraft simulators for SD training be explored.

- Aircrew training in both crew coordination and scanning be intensified.

- All aircraft be fitted with audio warnings on the radar altimeter.

- The introduction of the NVG HUD continue to be pursued.

- The development of hover locks and similar devices to reduce workload continue.

- A helicopter specific instrument panel be developed (including the provision of hover and drift information).

- Research into the specific causes of military rotary-wing SD and potential solutions continue.

- A further similar study of the Class A-C accidents be instituted in 1997 (covering the 5 years between the end of our study and April 1997).

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Appendix A.

Accident summary form.

ACCIDENT SUMMARY FORM

Accident Number:

Investigator ID:

SJD	JSC	NRR

What role did SD play during this accident (check ONE box only):

CLASS 1 'Major'	CLASS 2 'Subsidiary'	CLASS 3 'Incidental'	CLASS 4 'Not present'	CLASS 5 'Unknown'

Definitions:

- Class 1. SD was the 'major' component of the accident sequence (by which it is meant that all other contributory factors would normally have been overcome without mishap).
- Class 2. SD was a 'subsidiary' component of the accident sequence (by which it is meant that other contributory factors would have led to a mishap in any case - but SD made the accident sequence more difficult to deal with or the outcome more severe).
- Class 3. SD was an 'incidental' component (by which it is meant that SD occurred but did not affect the outcome).
- Class 4. SD did not occur.
- Class 5. Absolutely unknown.

How confident are you of this classification (check the highest 'certainty level' applicable):

'LIKELY TO BE RIGHT 95 TIMES OUT OF 100 OR MORE'	'LIKELY TO BE RIGHT 3 TIMES OUT OF 4 OR MORE'	'MORE PROBABLE THAN NOT'

Primary cause of accident:

HUMAN ERROR	MATERIAL FAILURE	ENVIRONMENTAL CAUSE

Is there any evidence of either of the following being present at the START of the incident (IRRESPECTIVE of outcome)?

	YES	MAYBE	NO
Distraction from Within the cockpit			
Distraction from Outside the cockpit			

QUESTIONS ONLY FOR ACCIDENTS IN WHICH SD PLAYED A MAJOR OR SUBSIDIARY ROLE

Would the accident fall into any of the following Safety Center categories?:

SCAN	ORIENTATION ERROR	ESTIMATE

Definitions:

- Scan: Improper direction of visual attention inside or outside aircraft; i.e. too much or too little time in one area.
- Orientation Error: Failure to properly execute procedures necessary to maintain or recover orientation in flight environments known to restrict visibility; e.g. snow, dust, IMC, black hole and over black water.
- Estimate: Inaccurate estimation of distance betwen objects or rate of closure with objects.

Did the disorientated pilot.....

	YES	MAYBE	NO
misjudge his altitude?			
misjudge his speed?			
misjudge his rate of descent?			
misjudge his angle of bank?			
misjudge his pitch angle?			
misjudge his clearance to the ground or a terrestrial obstacle?			
misjudge his clearance to another aircraft?			

	YES	MAYBE	NO
Were BOTH pilots disorientated?:			

How would you classify this episode?:

TYPE 1 (Unrecognised)	TYPE 2 (Recognised)	UNKNOWN

If you feel able to estimate the length of time for which the pilot might have been disorientated without being aware of his condition, please do so:

Seconds

Which of the following factors contributed to the disorientated pilot(s) misperceptions?:

	YES	MAYBE	NO
A visual ILLUSION - i.e. visual cues that were actively misleading?			
INSUFFICIENT visual cues - i.e. visual cues that did not actively mislead the pilot but which were insufficient to alert him to the correct situation?			
Provocative aircraft manoeuvreing?			
INSUFFICIENT vestibular cues?			
A vestibular ILLUSION?			
Visual limitations with use of NVDs?			
Failure to attend to symbology in NVDs?			
Misinterpretation of symbology in NVDs?			

Were any of the following situations involved?:

	YES	MAYBE	NO
Whiteout?			
Brownout?			
Flicker vertigo?			
Illusion of climb due to downwash of rain or snow?			
Illusion of sideways movement due to downwash over grass or other surface?			
Illusion due to sensor being remote or due to sensor movement?			
Unintentional aircraft movement?			

Would any of the following have reduced the chances of an accident (or have reduced its severity)?:

	YES	MAYBE	NO
Injected symbology in NVGs (alt, rocd, hdg, airspd, attitude)			
Height Audio Warnings			
Drift indicators			
Improved aircraft stability systems (e.g. hover 'lock')			
Peripheral Vision Device			
Improved 'standard' instruments			
Better internal lighting			
Improved NAVAIDS			
Better visibility devices on aircraft			
Better scanning			
Better crew coordination			

Appendix B.

Specific data obtained from USASC computer.

APPENDIX B

Specific data obtained from USASC computer

Accident classification
Period of day
State (US state or foreign country)
Aircraft type and series
Total cost
Mission of flight (combat/training etc)
Injuries - mil occupants only - fatal
- disabling
- non-disabling
- missing/pd
- not injured

Terrain
Data at time of emergency - altitude (agl)
- airspeed
- flt duration

Phase of operation when termination occurred
Phase of operation - emergency
Accident cause factors - material
- human role
- environmental
- scan
- orient
- estimate

Personnel factors:
Aircrew sleep in last 24 hrs
Aircrew flight experience
- total time
- in last 30 days

Lab test results
disease defects
sex of handling pilot

Data at time of occurrence:
Sky condition
Horizon
Visibility
Obstruction to vis (natural)
(artificial)
Sig weather